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Touching creativity; a review and early pilot test of haptic tooling to support design practice, within a distance learning curriculum

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KEYWORDS

Augmented haptic tooling; design practice; distance learning; experiential practice; haptics in education

ABSTRACT

Machine haptics has been shown to assist and enhance human–computer interactions. Research from previous studies in the field of haptics has focused on developing a user’s sense of realism of touch when using a haptic device. This paper examines the use of haptics for education, specifically for creative online education. The paper is presented in two parts. First, a review of literature was conducted and used to aid the rationale and underpin the design of a pilot test. Second, a pilot test was designed using a single-point kinaesthetic haptic device with a haptic rendered interface, to support the assembly of a virtual design prototype. The pilot test proved to be extremely valuable in creating and developing a rich virtual environment for non-sighted and sighted participants to use. The results from the initial pilot test showed that although users were positive about their experience of using the haptic device, there were improvements to be made to the interface to enhance the user experience in the next phase of testing.

1. Introduction

Trevor Barker (2008) asserts that ‘In Higher Education today, increasing reliance is being placed upon the use of online systems for learning and assessment’ (p. 5). This statement is particularly relevant to distance and online education institutes, who offer interactive online systems affording new and innovative ways to approach education and to support a range of academic subjects. However, the use of online systems can also leave many learners lacking in a richer more hands-on experience. Applied and creative subjects such as art and design can be seen to lack a richer hands-on experience. Lowenfeld (1952) states ‘... how fundamentally important it is for teachers to realise that the nature of creative expression is bound up with haptic perception whenever this is the artist’s basic and habitual mode of experience’ (p. 84). Lowenfeld’s statement is particularly pertinent for the communities of non-sighted (NS) students registered on creative and applied subjects at the Open University (OU). For these students, it is important that they are offered full access to all technology-

enhanced learning (TEL) tools, tools which can enhance their learning via credible hands-on experiences set within the creative process.

This paper reports on a literature review and a pilot test of haptic rendered interface used by distance learning design academics. The haptic application was designed to aid users to assemble a prototype at the early stages of design using multimodal¹ feedback. The following sections outline a review of pertinent literature and research questions, followed by a description of a haptic beta test conducted with distance design academics employed within the faculty of STEM at the OU, Milton Keynes, UK. Design academics who were invited to take part in the study offer an open and insightful review of the haptic technology and its validity to aid NS students registered on design and engineer programmes at the OU.

1.1. Research questions

This study used the following two research questions. The first question was used to guide the literature review and the second research question was used to drive the quality test.

RQ1. Can the field of *applied* distance education exploit the affordances of haptics to enrich students' learning experience?

RQ2. Can a novel virtual haptic rig assist users to assemble a virtual prototype in the early stage of design?

1.2. Methodology; framing the review

The literature within the area of machine haptics (MH) has shown rapid growth and maturity over the last decade. The body of work is interesting, but also wide ranging and reaches beyond the limits of this paper. The literature was categorised in three main themes, used to frame the body of research: (1) haptics, (2) haptics as TEL and (3) haptics and the design industry.

1.3. Literature review

A database and bibliographical search examined peer-reviewed papers, with particular reference to works published within the last 30 years. As this study used a desktop haptic device, varied publications were reviewed specifically based on kinaesthetic force haptic device (desktop). This review was actioned to further understand the state-of-the-art desktop technology and to further understand the types of applications used by this device. All duplications were cross-checked and eliminated. Table 1 highlights the composite results of the individual searches.

1.4. Haptic perceptions (human and virtual)

There are two main subcategories of human haptic modes: cutaneous (*contact with nerves under the skin and feelings from the skin, e.g. temperature, vibration, pain*) and kinaesthetic (*body and limb positioning in space, e.g. applying pressure and feeling*

Table 1. Collated reference results table showing dates of collection and source with numbers of papers and refined numbers.

Search keywords/ phrases (since 2012–2017 – to include empirical and theoretical)	ERIC results (No.) (number correct within time frame of the search)	JSTOR results (No.) (number correct within time frame of the search)	ScienceDirect.com (number correct within time frame of the search)	Sum total of searched studies	Sum total of refined works selected for further analysis
Haptics & TEL	222 refined to 8	2058 refined to 10	102 refined to 9		
Haptics & education/ open distance learning	33 refined to 5	18 refined to 5	3 refined to 1		
Haptics and the design industry incl. haptic drawing and modelling, concept generation	19 refined to 7	616 refined to 7	42 refined to 5		
Subtotal unrefined	274	2692	147	3113	
Refined total	20	22	15		57

weight). The use of physiological touch (human haptics) is often an unconscious act, and the somatosensory² system simply reacts to the environment we are in. Without thought, we change from one haptic interaction to another to action mundane handling processes such as reaching for a coffee cup, and we do this without deliberate thought and often without looking at the object. First, we would reach for the cup (*kinaesthetic*), the hand would naturally span the width of the cup (*kinaesthetic*) and the skin would feel the warmth (*cutaneous*), raising the cup to the mouth (*kinaesthetic*), feeling the warm liquid on the lips (*cutaneous*) and lowering the cup back down (*kinaesthetic*).

Prior to the early seminal works of Klatzky and Lederman (2003), there was a limited understanding of the physiognomies of human touch. Within Lederman and Klatzky's (1993) paper, they specifically discussed human exploratory procedure, and the commonalities of manual handling have been defined into six separate elements: weight, volume, texture, temperature, contour and form. Further to this, Klatzky and Lederman (2003) found that using a particular manipulation of an object was not coincidental, in that humans have specific hand movements to understand the properties of different objects, e.g. single finger tracing a global shape, unsupported holding of a shape to understand weight, etc.

1.5. Haptics (virtual reality)

Over the last 20 years, haptic technology has been designed to assist human–computer interactions and to widen the scope for multimodal sensory interactions. There are many variations of haptics which can be divided into two haptic device categories:

- *Kinaesthetic* ground-based/desk-mounted haptic, e.g. Geomagic Touch device, Falcon Novint (House, 2017).
- *Cutaneous* body-mounted haptics, e.g. Tactavest (Lindeman, Yanagida, Noma, & Hosaka, 2006)

The design community are relatively recent users of MH. However, due to the similarities in the tactile-led design process, haptics are proving to be a valued interactive tool. Desktop graphical user interfaces (GUI, pronounced gooey) are becoming more and more sophisticated at communicating rich visual data to the user but lack any further form of sensory stimulus. Visually led users can be seduced by the vibrancy of colour, complex imagery and information being conveyed, and as most GUI systems are visually led, this is quite a load on one sense. Many different haptic computer scientists have disseminated dialogues regarding the loading of information on to one sense. Brewster (2006) states:

...we are able to deal with an enormous amount of complex information of many different types without difficulty. One reason for the problem is that computers communicate solely by graphical output, putting a heavy burden on our visual sense which may become overloaded. (p. 211)

Oakley, McGee, Brewster, and Gray (2000) elaborate on this by stating Subjective workload measures showed that participants perceived many aspects of workload as significantly less with haptics. It appears to be logical that as we have five senses to engage with the physical world then the more sensory channels we use to interact with technology, the further we can assimilate real world sensory interactions allowing users to use the technology in a more innate manner. (p. 2)

1.6. Haptics and TEL

The use of TEL has been heavily used in e-learning environments to engage students with a variety of learning abilities and learning needs. The Higher Education Academy (HEA) report that TEL input needs to meet learning and teaching needs from registration to assessment stages. Chan et al. (2006) have a view which considers that the increased use of ubiquitous technologies, such as mobile phones, may create a turnaround where younger students may wish to use the same technologies in the classroom as they use at leisure. They state personal handhelds create the potential for a new phase in the evolution of TEL, marked by a continuity of the learning experience across different environments.

The advancement of TEL environments (TELE) using GUI to recreate and mimic real-world teaching environments has been shown to have flexibility across degree programmes and to be honed to become useful for applied studies when haptic technology is added. The HapTEL project offers a wide range of haptic applications to provide novel haptic interfaces for new users. However, this area is extremely new and still in its infancy.

1.7. Haptics and education/open distance learning

Many of the e-learning systems' GUI interaction levels, as previously stated, are limited to either mouse clicks or keyboard commands for navigational purposes. Hamza-Lup and Adams (2008) assert that the 'Lack of engagement may lead to a lack of students' interest and understanding' (p. 2).

The literature studied so far has offered the uses of virtual reality (VR) and how they may adapt to the complex idiosyncrasies of teaching and learning. To date, there are

very few empirical studies examining how haptics may assist distance learning or how it could affect learning at a distance through higher levels of dynamic engagement. Hamza-Lup and Adams (2008) have stated that the lack of engagement through a more passive interactive tool such as a keyboard or a mouse could disengage students or allow for attention drifts when studying. Haptics provides a more innate sense of interaction and allows the user to feel more hands-on in a first-person context, so users can manipulate 3D objects and move around as a mimicry of real-world interactions.

The use of haptic tools to support education is not a new concept; however, Steven Wall and Stephen Brewster (2006) examined haptics to support disabled users. Their specific research study featured working with haptics to assist NS learners to gain hands-on experiences with graphs and charts. Wall and Brewster worked with single-point haptic device to connect with bar charts and to then hear and feel quantitative results. The results were encouraging but limited to connected haptic feedback; future work was aimed at examining scatter graphs and unconnected or linked charts.

Minogue and Jones (2006) ask, 'how might haptics affect learning?'. In response to this question, Minogue goes on to note that within the early cognitive stages of learning, touch can play an active part in enforcing the learning and enquiry to retain the taught material. Minogue highlights the success of haptics when used as an applied training tool shown in surgery, veterinary and military use. The use of the haptic probe can easily simulate surgical tools and force pressures of tissue manipulations and palpitations. Minogue and Jones (2006) state 'This approach may also be useful for complex, three dimensional motor skills that are difficult to explain and describe verbally or even visually' (p. 333). It has been acknowledged that there is a precedence of teaching and learning via simulated environments, environments which could be designed to simulate real-world touch-based activities. To that end, haptic interactive tools could be well placed to offer the potential for learners to work with simulated touch with objects perceived to be untouchable, e.g. from planets to microscopic cells. This type of touch-based simulation could be seen as highly desirable to enhance distance learning programmes where users often work with simulated virtual learning environments (VLE).

1.8. Haptics and the design industry

Mitchell, Inouye, and Blumenthal (2003) state that the start of a creative act is the escape from one range of assumptions – a context – often with the aid of another context seemingly at odds with the first, but that provides a new way of viewing what we already thought we understood. From the germinal stages of developmental production, creative processes can often be a series of underfinished works from which designers select ranges of creative concepts to work on further. Often 3D concepts are worked on using some form of digital intervention. The difficulty of working with digital 3D graphics, as a work-in-progress tool, is that it is almost purely viso-centrally driven. In other words, designers cannot gain a handle of elements of the model such as weight, movement or surface by viewing it from a PC screen. All of these elements, however, can be important to the overall model development. When a design concept is situated within a larger design cycle, the earlier the designers have an opportunity to gain hands-on interactions, the further they develop their understanding of the concept as a whole. Figure 1 shows a simplified version of the Diamond D classic design development

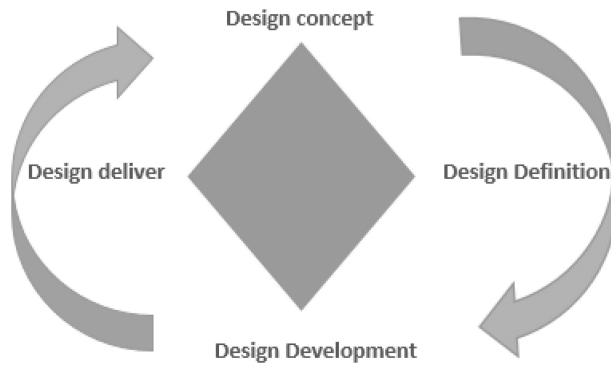


Figure 1. A simplified Double Diamond Design cycle (Council, 2017).

process. The haptic prototype assembly tool has been designed to be used as part of the early 'design definition' of the Double Diamond cycle.

Tillander (2011) asserts that technology processes, tools and interfaces rekindle an interest in creativity and its expression, as exemplified by the many online activities that are engaging creative innovation. Papert (1987) considers the opportunity to engage with systems and an array of 'objects to think with' (p. 20). Papert's comments predate high-speed interactive technology, but if we consider the concept of having an object to think with and extend this to technological functions, then they could allow us to consider how technology could be better used as an integral part of the ideation process, as well as acting as a manufacturing production tool. Scali, Shillito, and Wright (2009) and Cheshire, Evans, and Dean (2001) used haptics working with a design brief in the preliminary stages of craft making and the design cycle. From both of these studies, the results were mixed, but the evaluations from users were encouraging, in that even the most hardened crafts-man became more hands-on in the digital realm using haptics.

Jagnow and Dorsey (2002) have developed a sculpting system which works on the users' creative intuition. By increasing the speed of modelling, refresh and manipulation updates, the haptic sculpting device enables the user faster sculpting and building capabilities to offer more intuitive sculpting in real time. Therefore, a user can mould and model a large form, manipulate it, review and repeat the process in real time with a timely update and refresh of the system.

Therefore, it could be asserted that there is potential to use haptics to enhance applied discipline study. The main aim of this research project was to review a body of literature using specific research questions and to then develop a haptic interface with which it would be possible to test the impact of the touch to examine 3D objects within the virtual realm. In answer to the first research question posed in this study, it has been shown that haptic technology has been successfully used within the industry of design, and beginning to attract interest in education, shown in seminal works by Minogue and Jones (2006) and Wall and Brewster (2006). Specific TEL projects, such as the HapTel (San Diego et al., 2012), have spotlighted haptics to show the capacity of haptics to enhance immersive learning. However, other haptic researchers have shown that students' activities and access to the virtual realm can aid students with varied ability needs. (Amirabdollahian & Johnson, 2011; Barfield, 2009; Bordegoni & Cugini, 2005; Brewster, 1994; Burdea, 2000; Chan et al., 2006). The following outlines a pilot test which was

conducted with three design academics employed at the OU. The pilot test results from this study were used to further develop the haptic interface so that it could be used by sighted and NS design students to extend their access to computer-based study.

2. The shape assembly pilot test, settings and procedures

Design associate lecturers ($n = 3$), all participants were females, all employed at the OU, were invited to join a pilot test of a 'prototype assembly' haptic rendered environment. Participants involved in the pilot test were sighted, and only one participant's sight was aided by spectacles. The participants' mean average (M) age = 54 years, SD 6.5. Two out of three participants were right hand dominant, and one participant was left hand dominant. The haptic device was used equally by both left and right hand dominant participants. None of the participants were informed of the test protocol prior to the test, and none of the participants had any experience of using any form of haptic device prior to the test. .

All participants gave full consent to take part in the study, and due attention was given to the Open Universities ethics procedure (HREC/2016/2276) and data storage policy.

Prior to the pilot test, all participants were given full training instructions, and all training techniques were read from script by the test facilitator. All participants were requested to use the 'Think-Aloud' technique throughout the haptic test.

2.1. Test equipment

As previously revealed, the haptic device selected for this study was the Geomagic Touch device which is a desktop device working with six degrees of freedom within the virtual environment. The rig set-up meant that the 3x participants were requested to sit at a desk, facing a large screen visual display unit. The users were requested to pick up the stylus from the housing unit in their dominant hand and work through shape assembly actions (Figures 2 and 3).



Figure 2. Image of Geomagic Touch device being used (author's own).

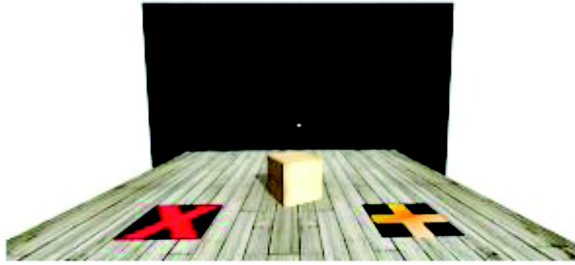


Figure 3. Pre-trial test environment.

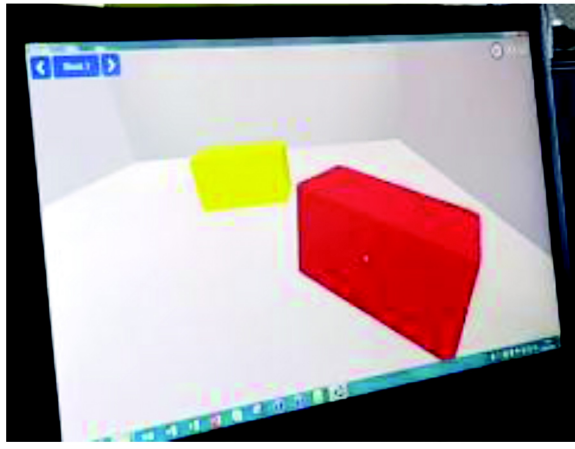


Figure 4. Screen shot of working haptic interface stacking blocks.

2.2. The shape assembly test protocol

Participants were initially asked to work through the pre-trial training environment which was a simple ‘pick up and put down’ task. The user picks up a cube and feels the weight and then places the cube down on a cross marked on the floor of the environment. The task assesses the user’s potential to be able to use the haptic device to pick up and place a 3D cube on a given target.

After the pre-trial task, participants were requested to work with the shape assembly test, and all ‘Think-Aloud’ feedback was recorded via an audio device. The shape assembly test requested participants to assemble four 3D blocks to form a prototype of a chair. Two foundation shapes were given, and users could call for two more shapes by depressing a space bar button. To navigate around the haptic rendered environment, participants could use the arrow keyboard keys. Using these, they would be able to access different views of the prototype, thereby allowing them to push and pull the blocks to tidy up the overall construction.

A timer was located in the top right-hand corner of the interface screen; this recorded the time taken to complete the whole construction. Once the construction was complete, the screen closed and a final time was displayed (Figure 4).

3. Results and evaluations

Times taken by each participant were 7,8 and 9 minutes ($M = 8$); the longest duration time was from one participant who chose to drop shapes one at a time but kept forgetting the call button. The same participant in her Think-Aloud feedback noted 'awe... I keep forgetting to press for a new shape and then I go looking for it' (1, 2017).

From the analysis of the recordings of the Think-Aloud feedback, two significant modifications were actioned as a result of the pilot test: (1) Technical issue of shape jitter – each of the 3D shapes when picked up and held in virtual space for longer than a few seconds began to jitter and shake. This was distracting for the user and a technical fault in the software communication with the haptic device. The developer reviewed the shape technicality and smoothed the links between haptic device and haptic environment. (2) Assistances for disability – participants reported that it would be more beneficial to users if more sounds could be added to the environment. To that end, three further sounds were added to the environment: (i) a foundation block – a dull sound, (ii) a block connecting sound – a ping and (iii) a completion sound – a higher pitch blend of sounds.

3.1. Qualitative results

This study was presented as a beta trial, and as such it has offered a useful response on the usability of the haptic technology, which will allow development of the haptic tool and interface for future trials with OU design students who are NS and sighted. The following presents the qualitative results selected from various forms of qualitative data, Think-Aloud feedback and pre- and post-evaluation feedback.

The Think-Aloud feedback recordings showed that the participants were initially tentative about moving around the virtual bounded space using the probe. They took a few minutes to orientate themselves within the space and to gather their immersive sensibilities. Once accustomed to the space and using the probe, participants were keen to explore all the walls and ceilings of the space using the probe, and they were surprised when the environment responded by offering the user the same touch feed-back as would be expected in a real-world context. Participant 2 asked 'Can I feel [*sic*] the walls and floor as a resistance?' (2, 2017), and Participant 1 stated 'I am going to try and pick this up now...oh its moving...' (1, 2017).

Once participants had probed the environment fully, they were then more confident in interacting with the 3D shaped blocks centred on the floor of the space. Two of the participants felt that they needed to draw on the facilitator to remind them of what to press and how to react and felt that they had to pause to collect their thoughts before acting on the instructions as they seemed to be tentative about over-forceful use of the probe and the virtual environment. This disappeared once the participants had been using the tool for 10 min or more, and they were observed to relax back in their seats and not ask so many questions.

I am glad that I have the guidance verbally, or even just someone there, as I don't want to break it... (3, 2017)

One of the participants offered in the test Think-Aloud dialogue that she usually needed a break with motor skills work due to a personal injury, but she felt ok with the stylus and the force actually helped her to move smoothly. All the participants stated how they felt they were confident in the knowledge that the environment was solid and how the 3D shapes' weight aided their relation to the VR from their understanding of the real world. All three participants felt intrigued by the changing camera view of the probe in connection with the 3D environment, but they also felt this distracted them after a short time. Observations showed that when each user changed the camera angle, they seemed to move nearer to the screen, and they angled their heads in relation to the camera view. All participants reported that by using the probe, they felt physically drawn and connected to the visual environment in a manner that made them feel more 'present' in the environment, although this was only reflected and commented on after the pilot trial.

Given all of the feedback and all that the qualitative evaluations revealed from the pilot test, there were some areas highlighted to revisit and develop further to allow for a more user-friendly experience, as seen in Section 3. However, the benefits of using the haptic interface were apparent from the reasoned professional feedback from each participant.

I came home really enthused by the idea, it certainly seems to be the way forward. So exciting that we have been able to get computer technology this far within Education. The opportunities as a tool for design for distance learners are endless as far as I can see. (3, 2017)

I believe that haptics will be at the forefront of developments in technology that will have a big impact on society's future and can see this being used alongside other developing fields within design and technology etc. such as 3D printing, fabrics that integrate digital technology within fashion, textiles that are sustainable and building materials that look at being low impact. (1, 2017)

I find this fascinating and an area that stimulates my own creative thinking. (3, 2017)

The feedback from Participant 3 was encouraging; this particular participant seemed to make some interesting connections between the tactile augmentation and the potential use of touch-led interactions to engage and stimulate creative tactile thinking. This feedback endorsed the types of responses we were hoping to achieve and therefore take the development of the haptic device on to further work.

3.2. Conclusions and future work

The seminal works of Klatzky and Lederman (2003) have spotlighted the human physiological effects of haptic interactions in our everyday world. In the last decade, the use of the term 'haptics' has deferred to the development of touch-led technology, technology which can augment human touch interaction with VR environments. Key empirical studies in this field (Amirabdollahian & Johnson, 2011; Brewster, 2006; McGee, Gray, & Brewster, 2001) have all highlighted the potential for haptics to not only aid immersive learning but assist *ability needs* learners to access VLE. This paper has drawn together a range of literature from the field of haptic technology and works from human haptics to further understand and to analyse all facets of a

learner's/user's interaction with digital data. Particular reference has been given to haptics used as a creative tool to aid educational and aid immersive 3D effect and to extend learner's interactive understanding of 3D concept generation. Studies presented by Oakley et al. (2000) appear to point to haptics as a tool which could lessen users' perceptions of work load and to aid NS users to interact with graphical systems. Works by Scali et al. (2009) and Cheshire et al. (2001) show how the haptic device has been used as a tool to augment creative touch and highlighted the uses of haptics to aid the creative practitioners' thought process at the germinal stages of conception and beyond the iterational process into full development. Jagnow and Dorsey (2002) offer the potential for haptics to increase the time it takes to produce a germinal stage prototype. Papert's (1987) discussion about the process of conception and allowing the designer/creator access to 'objects to think with' holds a strong resonance and correlation to the Design Council's Double Diamond Design process and to how designers commonly work with blank base objects or generic forms to ignite creative conceptions.

Haptics is not yet able to fully match the human haptic sensory perceptions; however, this study has revealed that technology is maturing and that there is strong evidence that haptics are being used inclusively to enrich learning and teaching.

It is possible to respond to RQ1 and RQ2 with a partial positive agreement. As the qualitative feedback from the participants revealed that they were enthused and even excited by the use of haptic probe and VR environment. This was confirmed by the results of the Think-Aloud feedback, which showed that participants were comfortable using the force feedback and were able to understand the use of the haptic feedback as part of the design process after a short time of using the tool.

The slight lack of agreement with RQ2 was due to the developmental additions and changes required to the technology and interface. However, the changes that came out of the pilot test were latterly shown to add value to the user experience, proving the pilot test to be worthwhile overall.

3.3. Future work

Further development and a brief trial test have been planned. The second trial will invite a group of FS, NS and visually impaired (VI) students registered with the OU 2017 (Engineering and Innovation School). The next phase of testing will work with a single-point haptic probe that works with a varied level of sight acuity design students ($n = 10$ NS/VI, $n = 10$ FS). The final empirical trial aims to aid better accessibility and afford assistances to the digital environment, thereby enabling use by VI and NS students. The haptic assistances will be technically simple additions, e.g. heightening the hue of the blocks and receding the hue tone of the environment for VI users and heightening the force feedback for all users to easily navigate and perceive force feed-back. The main haptic testing working with assistive additions is felt to be a pertinent addition to the OpenSTEM Lab portfolio at the OU and to increase TEL for 'open access' learning and teaching for all.

Notes

1. Multimodal describes an interface which uses more than one sensory channel to interact with the system.
2. Somatosensory system – relating to or being sensory activity having its origin elsewhere than in the special sense organs (such as eyes and ears) and conveying information about the state of the body proper and its immediate environment and also relating to or being either of two regions in the parietal lobe that receive and process somatosensory stimuli (Miriam Weber.com).

Disclosure statement

No potential conflict of interest was reported by the author.

Notes on contributor

Lisa Jane Bowers is an inclusive designer, who also teaches undergraduate-level design at The Open University. For the last 8 years, she has studied the role of touch-led (haptic) robotics to afford greater access to 3D virtual data for non-sighted and visually impaired designer-makers. Recent works have been disseminated in the fields of technology-enhanced learning (TEL), and future works will make greater connections with haptic technology used to enhance mobile e-learning within the disciplines of Design and Engineering for sight-impaired learners.

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